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THE DEVELOPMENT OF RAPID SAND FILTERS IN OHIO[1]

By Philip Burgess

The early installations of municipal water works plants in Ohio generally were the results of requirements for fire protection, and but little attention was then given to the quality of the public water supply obtained. Within recent years, however, the rapid increase in population has caused appreciable and in some cases serious pollution of all surface waters in the state; and at the same time, there has been brought about by a campaign of education a much larger and fuller appreciation of the value and worth of a pure public water supply. Experience indicates that the rapid sand filter is best qualified for the purification of the comparatively turbid waters found in the Middle West, and it is the writer's endeavor to indicate what a prominent and important part in the development of the history and art of water purification by rapid sand filters has been played in the state of Ohio.

Possibly a few general remarks, relative to the growth and character of rapid sand filter plants in Ohio, will indicate how true this is. In this connection, it may be noted that a patent for the use of a coagulant in connection with the filtration of water was granted to J. L. Hyatt in 1884. In view of the fact that a satisfactory treatment of water by rapid sand filters requires the application of a coagulant, the beginning of the development of rapid sand filter plants for the treatment of municipal water supplies naturally followed the above date, and the first of such plants was constructed in the United States at Sommerville, New Jersey, in 1885. Of course, during the early history of the art, there was no assurance to the public that a rapid sand filter plant would produce satisfactory results and would render municipal water supplies of satisfactory quality for domestic use, so that nearly all such early municipal filter plants were constructed under guarantees of efficiency of results to be accomplished.

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[1] Read at Central States Section Meeting.

The first rapid sand filter plant in the United States provided for the purification of a municipal water supply, and constructed under a guarantee of efficiency was contracted for by the city of Lorain, Ohio, in May 1896. The first rapid sand filter plant constructed in the state of Ohio was built at Warren in 1895. The first municipal water softening plant constructed in the United States was built at Oberlin, Ohio, in 1903, and rapid sand filters of the pressure type were used to filter the softened water. The largest municipal water softening plant in the world and the second largest rapid sand filter plant in the world are constructed at Cleveland, Ohio, and have a capacity of 144,000,000 gallons daily. The third largest rapid sand filter plant in the world also is in Ohio, at Cincinnati, and has a capacity of 112,000,000 gallons daily. Moreover, the Cincinnati filters were the first muncipal filters designed for the application of wash water at high rates without any other means of agitation for cleaning the sand. In building the Cincinnati filters, a brass wire screen was placed over the gravel to keep it in place during washing. The first municipal rapid sand filter plant designed for high rates of washing, and constructed with deep, coarse, gravel layers over the strainer systems without superimposed screens for holding down the gravel during washing was constructed at Niles, Ohio, in 1910.

The first filter plant at which alum has been manufactured for use as a coagulant is at Columbus, Ohio.

The first municipal rapid sand filter plant at which the disinfectant qualities of common lime have been intelligently and knowingly utilized is at Cleveland, Ohio.

The first systematic investigation by a state board to determine the efficiencies of the filtration plants in a state was made by the Ohio State Board of Health in the years 1906–8.

Just as it is true, as indicated above, that the state of Ohio has done more to develop the art of rapid sand water purification than any other state, so is it true that the citizens of the state are now enjoying the use of larger rapid sand filter capacities than any other state. This is well indicated in the following table wherein are shown the filter capacities and the population served by rapid sand filters constructed in Ohio during the several periods indicated.

Table showing progress in construction of rapid sand filter plants in Ohio

PERIOD	POPULATION SERVED BY NEW PLANTS AT END OF PERIOD	DAILY CAPACITY OF NEW PLANTS (GALLONS)
1895	7,900	1,450,000
1896–1900	35,371	7,870,000
1901–1905	123,284	24,520,000
1906–1910	777,293	179,650,000
1911–1915	930,674	236,200,000
Total present daily filter capacity ..		449,200,000
Total population served in 1915.....	1,940,000	

Table showing percentage of population of state of Ohio served by rapid sand filters

YEAR	TOTAL POPULATION OF STATE	POPULATION SERVED	PER CENT
1900	4,157,545	43,900	1.1
1905	4,462,333	185,486	4.2
1910	4,767,121	945,819	20.7
1915	5,071,909	1,940,000	38.3

From the above tables it is shown that the first rapid sand filter plant was constructed in 1895 and had a capacity of 1,500,000 gallons daily. It served a population of 7900. At the present time the total filtering capacity of rapid sand filter plants now in operation or under construction in the state of Ohio is 450,000,000 gallons daily and the filters serve a population of nearly two millions. It is of interest to note that the total nominal capacity of filters now in operation or under construction in the state is sufficient to provide nearly 90 gallons of filtered water daily for every resident in the state.

Possibly the most interesting feature in connection with the construction of rapid sand filter plants in Ohio is the development which has been accomplished in the design and construction of the plants. As would be expected in the interval of time that has elapsed from the construction of the first plants to the present time, there has been a marked improvement in the design and arrangement of the units especially in regard to the treatment of the water before it is passed through the sand filters, and in regard to the size, form and construction of the filter tanks.

As previously stated, the first plant constructed in Ohio is of the Warren type and consists of units containing sand filtering beds supported on perforated metal plates. Beneath the filter bed bottom of each unit is a chamber into which the filtered water pours on its way to the main filtered water outlet. During washing water is turned under pressure into the clear water compartment beneath the sand and forced upward through the perforated plates and into the sand. Such a strainer system may be classed as an "open type strainer." The disadvantage of such a system is that it is difficult to get a uniform distribution of wash water throughout the entire area, especially in large units. The design is satisfactory for small units, but it is not entirely satisfactory for larger units on account of its excessive expense and because of the difficulty of obtaining a uniform distribution of the wash water over the filter bottoms, as they were originally constructed. This was especially true in the old units wherein the sand was supported on brass wire screens, having comparatively large aggregate openings.

The filters constructed at Lorain were of the Jewell type. The essential features of these filters were that the strainer systems were composed of perforated pipes containing sand valves placed at uniform intervals covering the filter bottom. Filtered water was collected in the strainer pipes and carried to a main storage reservoir. No filtered water compartment for collecting the effluent was provided beneath the sand. It is significant that many modern plants still are constructed using strainer systems of this type.

The advantage of this system is that the wash water can be applied at higher rates under greater pressure without danger of damaging the filters. Moreover, the design permits the construction of a second compartment beneath the filter to store the water for sedimentation and coagulation on its way to the filter. The disadvantage of this strainer system, which is of the "closed type" is that it sometimes clogs by growths or other foreign matter and that there is then considerable difficulty in properly cleaning the strainer systems.

A modification of this closed type of strainer is to be found in the Hyatt cone valves, such as are used in the filters at Geneva and Newark, Ohio. These valves comprise castiron cones about 6 inches high and 6 inches in diameter at the top, covered with brass, perforated hemispherical plates, and containing shot or fine gravel.

The principal advantage of these units is that they can be taken apart and cleaned without damaging the strainer system.

As shown above, the old Warren type filters contained no provision whatever for treating the water before it was applied to the filters, so that the only opportunity permitted for coagulation and sedimentation was as the water stood above the sand in the filters or by providing outside settling tanks. The period of coagulation provided in the filters was about fifteen minutes. Approximately the same period of time for coagulation was permitted in the compartment provided beneath the Jewell type of filters at Lorain.

Probably the greatest development in the art of water purification has been an appreciation of the fact that the burden to be placed upon the filters should be made as small as possible in order to accomplish the most satisfactory results at the least expense. Within reasonable limits, it is true that the percentage removal of bacteria and other impurities by the filters themselves is limited, so that, of course, the best results are accomplished by removing all possible impurities by preliminary treatment before filtration. This has been appreciated in the design of modern plants wherein the period provided for coagulation and sedimentation previous to filtration is frequently from three to six hours.

In the same way, there has been a marked development in the design of the filter tanks themselves. The phrase "mechanical filter," frequently applied to rapid sand filters, was derived from the fact that a stirring device, or mechanical agitator, was provided to stir the sand in the filters and thus to assist in the removal of impurities during washing. It is obvious that such a device required a circular filter tank. As early as 1889, it was recognized that air under pressure could be used to agitate the filter sand during washing and the application of this principle, of course, permitted the use of rectangular tanks in place of the circular tanks as previously required with mechanical agitators or rakes. This principle has proven of great value in reducing the construction cost of the larger mechanical or rapid sand filters, because it has permitted the use of reinforced concrete rectangular units occupying very much less area than is required for circular tanks of the same capacity.

It is significant of the development of the art of water purification that the last wooden tank filters now operating in Ohio, and provided with mechanical agitators, very soon will be removed and replaced by rectangular concrete tanks. The old filter plant at

Lorain was replaced some years ago by a modern concrete filter plant, and it is of interest to note that the results accomplished by the modern plant today are no more satisfactory than the results which were accomplished by the old plant, before its capacity was exceeded. Moreover, the cost of operation of the new plant is considerably in excess of that of the old plant.

In view of the disadvantages apparent in the closed type of strainer system comprising perforated pipes equipped with sand screens, or valves, engineers have endeavored to develop a strainer system of the closed type in which all parts would be accessible. The first strainer system to be developed along these lines in Ohio was used at Cincinnati, and comprised lateral concrete channels covered with perforated brass plates. The design permits the removal of the plates, and inspection and cleaning of all parts of the strainer system. Owing to construction imperfections, especially at the shoulders where the brass plates are supported, some engineers have reverted to the original form of closed or pipe strainer system. Possibly this action has been taken, in part, because of patents covering the use of depressed channels in filter bottoms.

A further important modification in the design of rapid sand filters was developed at Cincinnati and comprised the use of wash water without either air or mechanical agitation for cleaning the sand. Experiments conducted by Mr. J. W. Ellms indicated that when the wash water was applied at rates greater than 18 inches vertical rise per minute the entire sand body was thoroughly agitated and moved by the wash water, so that further agitation by mechanical means or by air under pressure was not required. It was thought at that time that the high velocity of the incoming wash water would require that the filter gravel, placed above the strainer system, be restrained in place by brass screens. Subsequent developments, however, have shown that the screens are unnecessary and during the past two years they have been removed and the gravel layers deepened.

This fact was appreciated in the design of the rapid sand filter plant constructed at Niles, in 1910, under the direction of the writer, where wash water is applied at a rate of about 24 inches per minute without any disturbance of the filter gravel which consists of coarse, deep layers not fastened down by screens.

In this connection it may be noted that not the least important development in the design of rapid sand filters has been in connection with the use of larger and deeper gravel layers. In the old Warren and Jewell type filters, such as were built at Warren and Lorain, Ohio, no gravel whatever was placed between the strainer systems and filter sand. This method of construction in fact was continued for a number of years, and until 1910 some filter plants were constructed without any filter gravel. The writer has known instances where the construction of old filters has been modified by placing gravel above the strainers with the result that much more efficient washing of the filters has been accomplished by the use of very much less wash water. It is undoubtedly true that the gravel layers play an important part in distributing the wash water throughout the filter area, as well as in keeping the sand from passing through the strainer system, so that the successful washing of filters, especially under high rates, may be largely attributed to the use of coarse, deep, gravel layers.

A considerable part of the expense of operating a rapid sand filter plant is incurred by the cost of the necessary coagulant, and any development which tends to reduce the cost of the chemical is, of course, an important advance in the art of water purification. The coagulant most commonly used is filter alum, or aluminum sulphate, which generally is purchased in crystalline form at a cost of about 9 cents per pound.

At the Columbus, Ohio, Softening and Rapid Sand Filter Plant, filter alum is manufactured directly at the plant. The alum manufactured at the Columbus plant is not filtered or crystallized but is applied in the crude liquid form. It is obtained at less than one-half the cost of the finished manufactured product, and, on account of the fine clay contained in the liquid, has proven even more efficient than the clear crystallized chemical.

Another notable development in the art of water purification has been accomplished by the introduction of disinfectants or sterilizing agents. The three disinfecting agents which have been used on a large scale to disinfect municipal water supplies are hypochlorite of lime, liquid chlorine and quicklime, or calcium oxide, and the use of these germicides has become so universal that it is the exception where a filter plant effluent is not treated in this manner. The most common treatment is with hypochlorite of lime, or with liquid chlorine gas.

The municipal softening plant at Columbus, Ohio, has offered unusual opportunities to study the germicidal effect of quicklime, which is used primarily to soften the hard water of the Scioto River, but which is found also to destroy bacterial life in the treated water by eliminating the carbonic acid which appears to be necessary for sustaining such life. Dr. A. C. Houston, Chemist of the Metropolitan Water Board of London, England, probably is the first observer to note such germicidal action of lime. He recommended the application of lime to river water in excess of the amount required to soften the water, thus causing a caustic alkalinity of the treated water, a feature which he considered to be necessary to obtain any sterilizing action by lime treatment.

In a recent engineering magazine, is an article by Mr. Hoover, chemist in charge of the Water Purification Works at Columbus, Ohio, showing the results of his experiences and experiments on the germicidal action of lime. Mr. Hoover's conclusions, as stated in the article, are thought to be of general interest,and are as follows:

CONCLUSIONS BASED ON EXPERIMENTS

1. When enough lime is added to water to absorb the free and half bound carbonic acid and to precipitate the magnesium content, the bacteria of the colon and typhoid group are killed in forty-eight hours after being so treated, provided the water does not contain large quantities of organic matter.
2. The germicidal action is effective in from five to twenty-four hours when an excess of 0.5 to 1 grain per gallon is added beyond that needed to reduce the temporary hardness to the lowest possible figure.
3. The intestinal organisms will not live in water containing no free or half bound carbonic acid.
4. Lime softened water inoculated with typhoid organisms or with crude sewage soon becomes free from them.
5. The action is selective in that certain harmless bacteria grow but the disease producing germs do not.

The sterilizing action persists indefinitely.

In a recent paper on water disinfection by chemical methods Mr. Samuel Rideal states the advantages of using chemicals that persist in their disinfecting action in the following words:

> It is at the same time a disadvantage, if a disinfectant however powerful in its first onset, is very evanescent, as many disease germs are strongly resistant and we know that the time factor is of extreme importance in sterilization.

It is apparent that quicklime has a great advantage over hypochlorite of lime or liquid chlorine as a germicide, because its action continues indefinitely so long as the lime treated water contains no carbonic acid, whereas, on the contrary, the germicidal action of the hypochlorite continues but a short time after the application of the chemical.

The germicidal action of quicklime, together with the appreciation of the value of softened water, have been utilized in the design and construction of the new water purification plant of the rapid sand filter type recently constructed for the city of Cleveland, Ohio. The use of lime to treat and soften Lake Erie water, which has an average total hardness of not more than 115 parts per million, is a radical departure from former current practice, because such water, especially in the Middle West where hard waters prevail, would be considered of satisfactory quality for domestic use without softening. It is reasoned, however, that owing to the considerable difference in cost per ton of quicklime and of alum, it is possible to use about four times as much lime as alum at the same expense. The lime, however, has a continued germicidal action, especially on intestinal bacteria contained in the water, and moreover, the lime will soften the supply, which will thus be made more desirable, at but slightly more expense than would be entailed by the usual methods of filtration, using a coagulant such as filter alum.

It is, of course, difficult to state where further developments in the art of water purification may be accomplished, but it is very apparent that the present stage of development is such that it is possible to treat even a badly polluted river water by rapid sand filters, and in conjunction with a sterilizing process, to produce a water very satisfactory in all respects for domestic use. It has been the purpose of this paper to call to the attention of the members of this Association how prominent a part has been and is being played in Ohio in the development of the art of purifying surface waters by rapid sand filters, because it is doubtful if the members appreciate the fact that in this state are to be found plants which represent practically all stages of advance in the design and construction of rapid sand filters. Moreover, such Ohio cities as have to solve the problem of obtaining a public water supply of good quality from a polluted surface water can approach the matter with entire assurance of its satisfactory solution by the introduction of a rapid sand filter plant either with, or without, some germicidal treatment as circumstances may require.